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AGRICULTURAL MEMORANDUM NO 946

J GLOSTER AND M FIELD

Newcastle disease - Part 4 - The importance of the size of poultry units on the airborne spread of the disease.

INTRODUCTION

Gloster (1982) posed the following question with regard to the likelihood of infection of chickens with airborne Newcastle disease (ND) virus.

Would a unit of 100,000 birds be at greater risk than one of 100 birds?

This memorandum investigates the problem from a statistical viewpoint. A brief description of the distribution of chickens in England and Wales is also given so as to provide a framework for the statistical analysis. Areas requiring further research are also identified.

THE CHICKEN INDUSTRY IN ENGLAND AND WALES

The chicken industry can be divided into two major categories, the egg producers and broiler producers. There are a large number of small egg producing units (and only a few very large ones) whereas broiler units tend to be much larger in size, see Table 1.

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Table 1. Distribution of the chicken population as a function of unit size (England and Wales 1979)

Egg Producers:

Unit Size	Number of units in size range	% National laying flock in size range
1 - 999	44,478	5.2
1,000 - 4999	1,517	9.9
5,000 - 9999	616	11.2
10,000 - 19,999	427	15.3
20,000 - 49,999	237	18.9
> 50,000	14	39.5

Total population 38.1 million

Broiler producers:

Unit Size	Number of units in size range	% broiler capacity in size range
1 - 9,999	762	3
10,000 - 19,999	190	6
20,000 - 49,999	278	18
50,000 - 249,000	220	43
> 250,000	15	30

Total capacity 46.9 million

Over the years there has been a move towards intensification of the industry especially in the broiler section. In the late 1960's it would have been unusual to have broiler units of 50,000 or more but the table shows that in 1979 there were well in excess of 200 such units.

Chicken farming is carried out throughout England and Wales but it tends to be concentrated in certain counties. This concentration has either occurred because of the location of nearby markets, available local foodstuffs or simply because a large manufacturer has invested heavily in a particular area. Table 2 gives the numbers of layers and broilers in some of the more heavily stocked counties. of England and Wales.

Table 2. The number of layers and broilers in some of the most prominent counties of England and Wales (1979)

County	Number of layers (millions)	Number of broilers (millions)
Suffolk	.7	3.7
Hereford	.9	3.5
Lincolnshire	1.9	2.6
Norfolk	1.3	2.6
Hampshire	2.7	2.3
Essex	1.3	2.0
Devon	1.9	1.7
Lancashire	1.9	1.3
E Sussex	$< .25$	1.1
Salop	1.7	0.9
Kent	1.4	0.5

Thus chicken units vary in size from a few birds up to hundreds of thousands and these units are often highly localized.

STATISTICAL ANALYSIS

The atmospheric concentration (n_o) of virus particles at a point downwind of a virus source is:-

$$n_o = \frac{aEN'}{uwh} \quad \ldots\ldots\ldots (1)$$

where a = factor allowing for a roughly gaussian distribution of particles concentration along and downwind ($\simeq$ 3)

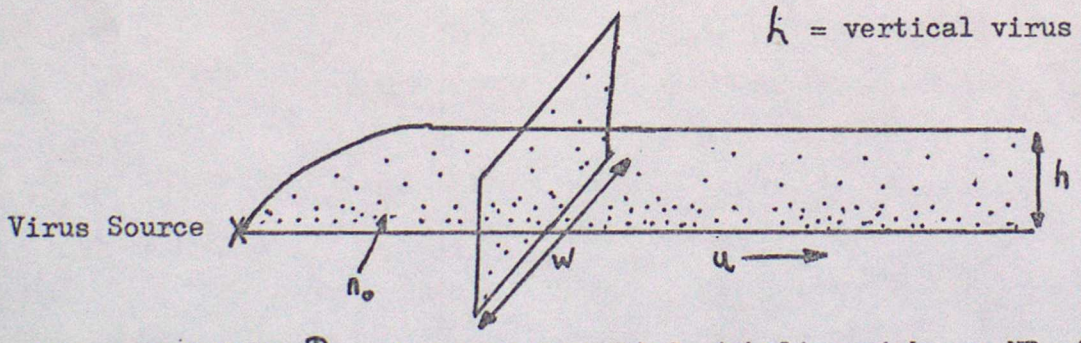
E = virus emission from one infected bird (number sec^{-1})

N' = number of infected birds

u = windspeed (m sec^{-1})

w = lateral virus plume width (m)

h = vertical virus plume depth (m)



The probability, P, of one or more birds inhaling airborne ND virus and subsequently becoming infected is:

$$P = 1 - e^{-n_o N r t m} \quad \ldots\ldots\ldots (2)$$

where n_o = atmospheric concentration of virus (number m^{-3})

N = number of birds inhaling air containing virus

r = breathing rate of a chicken (m^3 sec^{-1})

where t = length of time birds unhale virus (sec)

m = probability of an individual particle causing infection

The derivation of equation 2 is given in Appendix 1.

Assumptions

In order to solve equations (1) and (2) it has been assumed that:

(1) A single infected bird emits 10^4 particles per day into the atmosphere. Birds infected with Essex '70 (velogenic* virus) have been shown, Allan (private communication) to emit 3×10^5 ELD^*_{50} day^{-1} into the atmosphere. We have assumed that only a small quantity of this virus becomes and remains airborne as discrete particles. Further measurements are needed before a precise value of E may be used in calculating the potential for airborne spread of ND.

(2) By defining the meteorological conditions the values u, w and h can be obtained by reference to Crabtree (1981).

(3) The breathing rate of a chicken of 0.6 kg in weight is 10^{-5} m^3 sec^{-1} (500 ml/min). This value was measured by Kohn (1955).

(4) The probability, m, that an individual particle causes infection is thought to be substantially less than 1. In the calculations a value of 0.1 has been used. Further experimental work is required to ascertain its true value.

Solution of Equations

Using the assumptions above the equations have been solved for various virus emissions, numbers of susceptible birds downwind, exposure times to virus and different meteorological conditions.

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* For definitions see Gloster (1982).

The probability, P, of one or more birds, in a flock of chickens 5 km from a virus source, becoming infected can be deduced from Figures 1 to 3. To deduce p the following method should be used:-

Decide upon :-

(1) which of the following weather categories is applicable.

(a) highly unstable day with strong incoming solar radiation and a windspeed of 1.5 m sec^{-1} (Pasquill stability category A). - Use Figure 1.

(b) an overcast day with a windspeed of 5 m sec^{-1}. (Pasquill stability category D) - Use Figure 2.

(c) clear night with a windpseed of 2 m sec^{-2}. (Pasquill stability category F) - Use Figure 3.

(2) the number of birds that are on the threatened unit. (X axis on Figures 1 to 3).

(3) the number of birds that are emitting virus at the source (N'). Curves for different values of N' are given on Figures 1 to 3.

The probability of infection can then be read off the Y axis.

Results

(1) Large chicken units are significantly more at risk than smaller ones.

(2) The highest probability of infection occurs at night when the sky is clear and the windspeed is light.

The effect of distance from a virus source to susceptible birds

Figure 4 gives a comparison between the probability of infection for two chicken units, one at 5 km and the other at 20 km from a virus source. In both

cases the units most be at risk are the large ones. The risk is smaller at the greater range, as one would expect, but cannot be ignored.

CONCLUSIONS

(1) Large units may appear to be more profitable than smaller ones. However, if there is ND in the area they are preferentially at risk. In the light of these calculations the siting of such units is important, in particular their proximity to other units. It was mentioned earlier that there is a tendency to invest in many units in a particular area. From the point of view of airborne disease security this is highly undesirable.

(2) It is also worth noting that in addition to the large units being more at risk than smaller ones they also pose a large threat to other units in the area as their potential virus output is higher.

(3) The calculations given in this paper are provisional because values for virus emission, E, and the probability of a single particle causing infection, m, are not known. To obtain the true potential for the airborne spread of ND values of these parameters are required from experimental work. However the main conclusions (see above) will be unaltered.

ACKNOWLEDGEMENTS

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Any comments or suggestions on this paper should be refered to the authors, Meteorological Office, London Road, Bracknell, Berkshire.

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Figure 1.

Weather: Highly unstable day with strong incoming solar radiation, windspeed = 1.5 m sec^{-1}, plume width = 1000 m, plume depth = 600 m (Pasquill Stability Category A)

Number of birds emitting virus = N'

Birds on threatened farm exposed to virus for 3 hours

Threatened farm 5 km from virus source

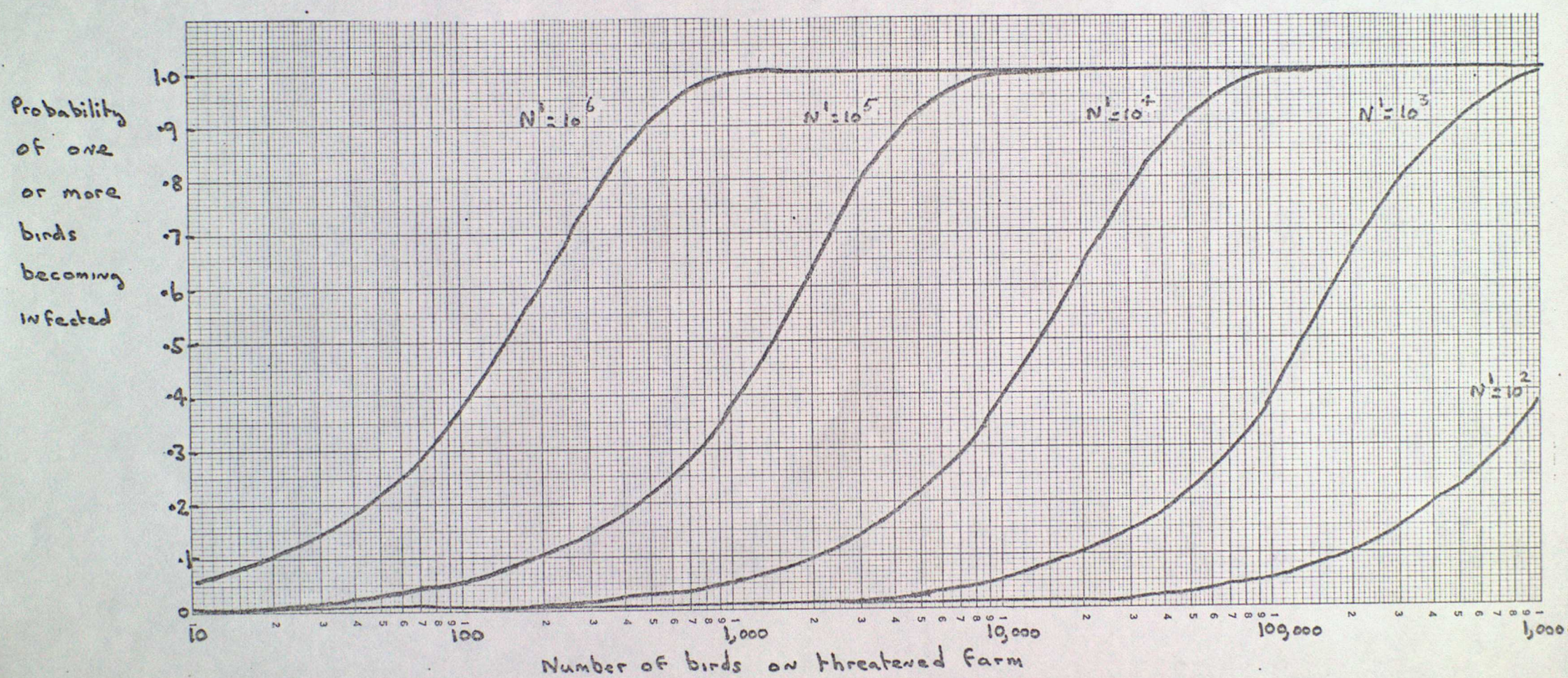


Figure 2.

Weather : Overcast day , windspeed = 5 m sec^{-1} , plume width = 300 m , plume depth = 150 m (Pasquill Stability Category D).

Number of birds emitting virus = N'.

Birds on threatened farm exposed to virus for 3 hours.

Threatened farm 5 km from virus source.

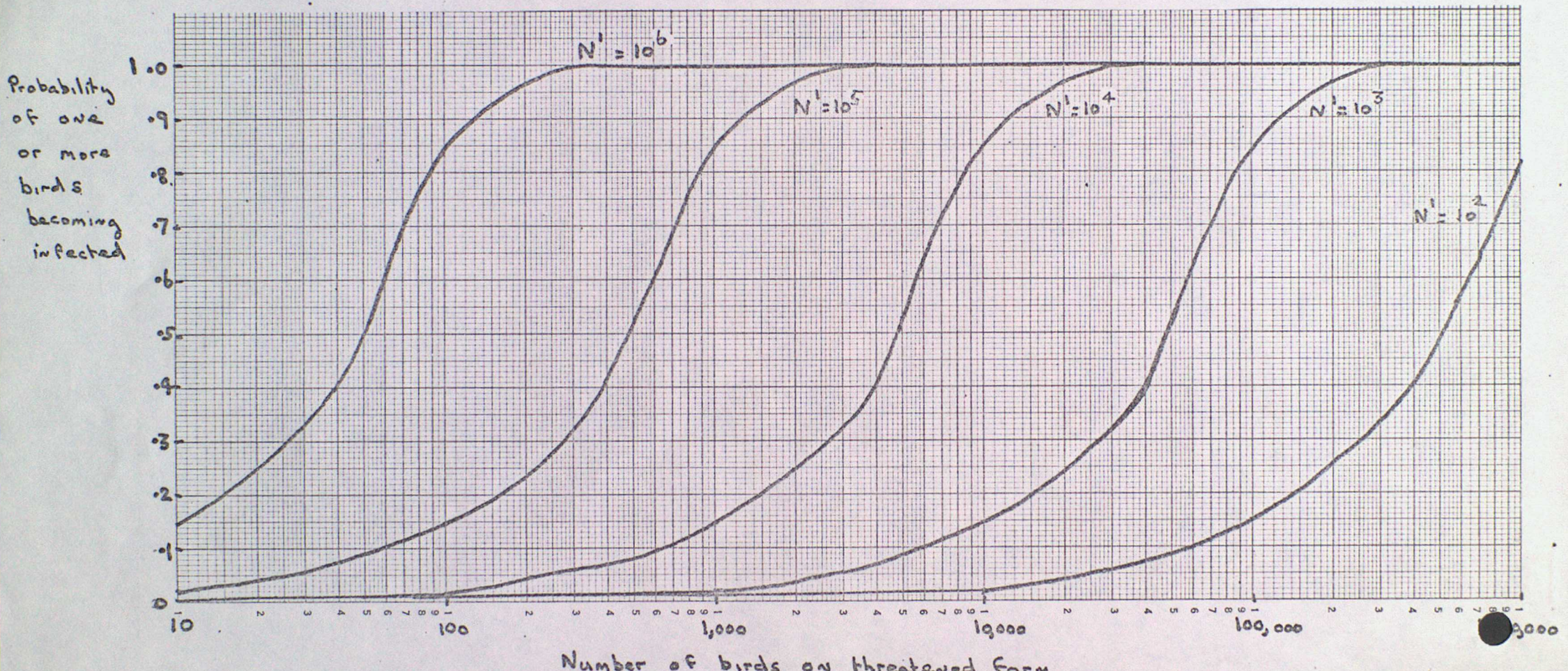


Figure 3.

Weather : Clear night, windspeed = 2 m sec^{-1}, plume width = 200 m, plume depth = 40 m (Pasquill stability Catagory F).

Number of birds emitting virus = N^1.

Birds on threatened farm exposed to virus for 3 hours.

Threatened farm 5 km from virus source

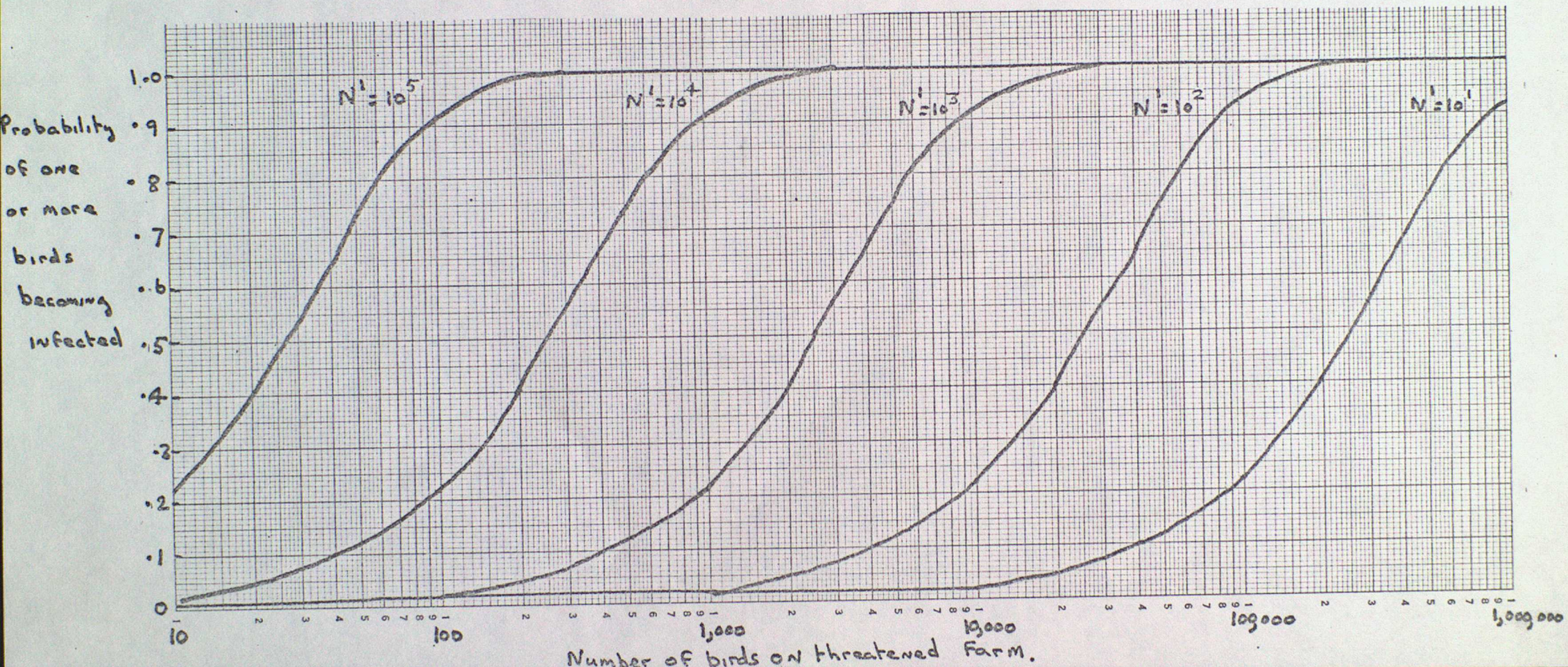


Figure 4. Comparison of probability of infection with number of threatened birds at 5km and 20km.

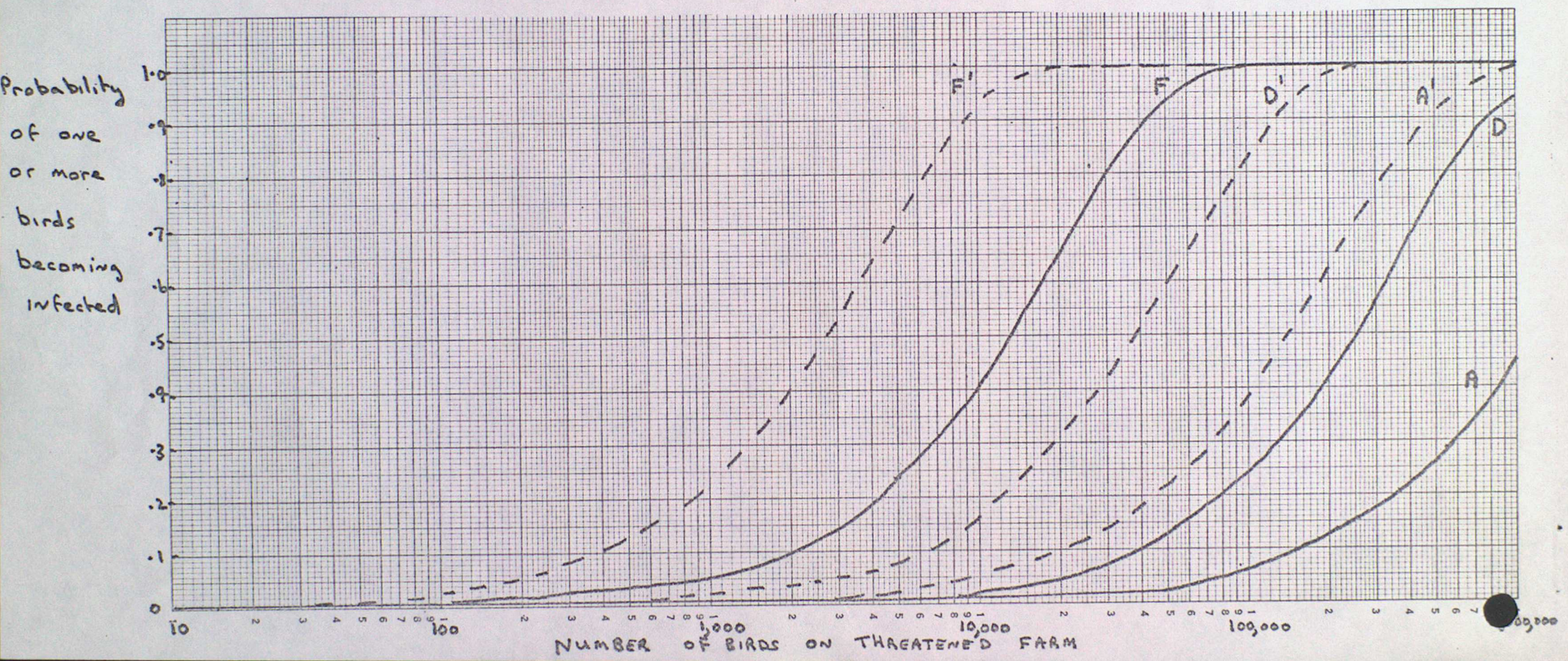
Virus source = 1000 birds.

Weather : Pasquill stability catagory A, D, F.

Prime = probability at 5km

No Prime = probability at 20km

Birds on threatened farm exposed to virus for 3 hours.



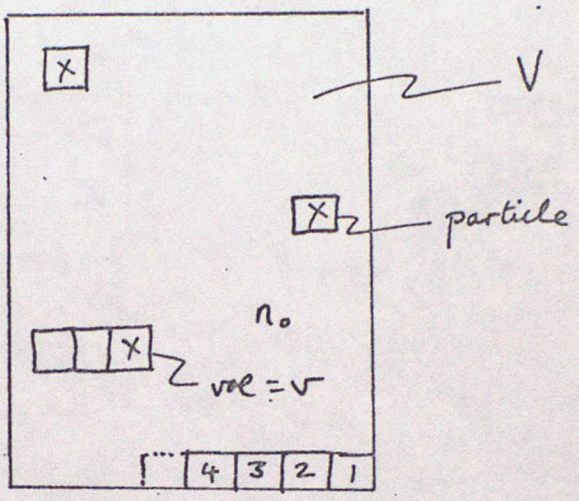
Appendix 1 - Probability of finding one or more particles in an arbitrary volume V

For a similar discussion of the statistics used in this derivation, see Nadel (1957).

Let n_0 = number density of particles

Let v = volume occupied by a particle

We select volumes of size v and see how many particles we find having examined the whole volume V.



p = probability of finding a particle in a volume $v = n_0 v$

q = probability of not finding a particle in a volume $v = 1 - p$

Now, the probability of counting r particles in n attempts, where p = probability of finding a particle in 1 attempt, is given by the Binomial Distribution,

$$P_r = \frac{n! p^r q^{n-r}}{r!(n-r)!}$$, where $n = V/v$, $p = n_0 v$, $q = 1 - n_0 v$

But, n is very large and p is very small.

$\therefore$ we can approximate by using the Poisson Distribution,

$$P_r = \frac{\mu^r e^{-\mu}}{r!}$$

note $\mu = np = \frac{V}{v} n_0 v = n_0 V$.

We need to find the probability of finding ≥ 1 particle in a volume $V = P_{r \geq 1}$

clearly $P_{r \geq 1} + P_{r=0} = 1$, where $P_{r=0}$ = probability of finding no particles at all.

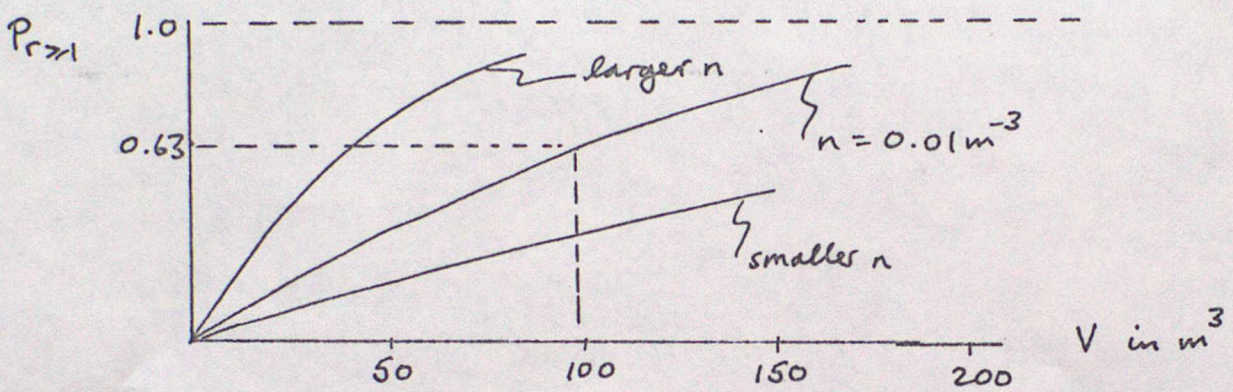
i.e. $P_{r\geq 1} = 1 - P_{r=0}$

$$P_{r\geq 1} = 1 - \frac{\mu^0 e^{-\mu}}{0!}$$

$$P_{r\geq 1} = 1 - e^{-\mu}$$

e.g. let $n_0 = 0.01\ m^{-3}$ (1 particle per 100 m^3)

if $V = 100\ m^3$, $P_{r\geq 1} = 1 - e^{-\frac{1}{100}(100)} = 0.63$



In a chicken house the arbitrary volume V represents the 'volume of fresh air which has been inhaled'. By fresh air we mean air that has not previously been exhaled by another chicken. This is a good approximation in a well-ventilated house.

Let the number of chickens $= N$.

Let the chickens inhale air for a time t.

Let r = breathing rate of a chicken = volume inhaled/time.

Then $V = Nrt$

We are interested in the probability of finding 1 or more particles in this volume.

This is $P = 1 - e^{-n_0 Nrt}$

Let m = probability of an inhaled particle causing infection $(0 < m < 1)$

Then the probability of infection in N chickens in a time t is given by,

$$P = 1 - e^{-n_o N r m t}$$